

OPTICAL CLINOMETER

[Optischer Neigungsmesser]

Author

Braunecker, Bernhard, Dr.  
Kipfer, Peter

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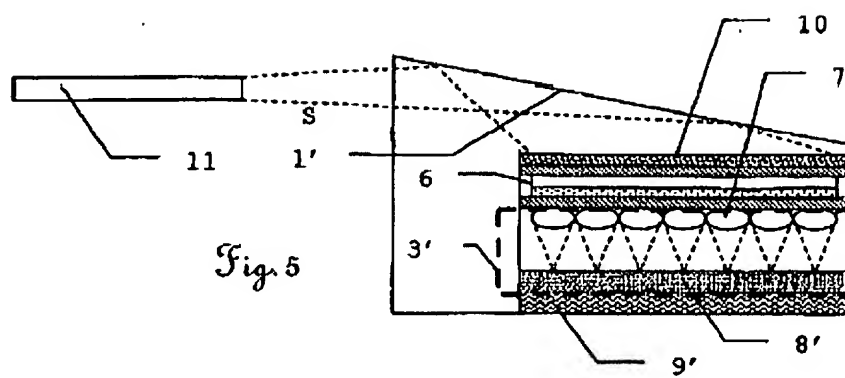
Author Affiliation : Leica Geosystems AG  
9435 Heerbrugg (Switzerland)

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**(54) Optical Clinometer:**

(57) In the case of an optical clinometer, an inclination independent medium (6), for example, the surface of a fluid is positioned in the pupil of an optical subsystem and a detectable wave front is built over this medium (6) on a detector (3'). A phase change of a radiation (S) emitted from a radiation source (11) is effectuated through the medium, whereby the change effect of the radiation (S) and medium (6) can result in reflection or transmission. With the help of a wave front sensor, an aberration of the wave front created through the medium (6) can be analyzed and compensated through an evaluation unit (9') or a detector (3'). A wave front sensor with a pre designed diffraction structure before every sub aperture increases the resolution capability and the compactness of the detectable angle region of the clinometer simultaneously.

Figure 5



## Description

[0001] The invention refers to an optical clinometer as per the title of claim 1, a process for measurement of the inclination of a device as per the claim 13, and a geodetic device with such a clinometer, a process for compensation of vibrations and/or static fluctuations and a wave front sensor for use in an optical clinometer as per the title of claim 20.

[0002] Clinometers of different designs have found applications for a long time in several domains in which the location of the device had to be considered. This is valid especially for measurements in the geodetic domain and in construction equipment.

[0003] In general, the optical clinometers of this genre based on the state of technology are designed with a fluid surface positioned in the pupil of an optical subsystem. With the help of this fluid as a medium, the phase change of radiation emitted from a radiation source is made, whereby the change effect of the radiation and medium could result in either reflection or transmission and, the following relationships hold:

$$\text{In reflection: } \Phi = 2.P(x)$$

In transmission:  $\Phi = (n-1) \cdot P(x)$

[0004] The dimension  $\Phi$  refers to the phase change,  $n$  refers to the refraction index of the fluid and  $P(x)$  represents the form function of the surface of the fluid, whereby it is defined as

$$P(x) = 2\pi/\lambda \cdot x \cos(\alpha)$$

$\lambda$  is the wavelength of the radiation;  $x$  is the internal pupil coordinate and  $\alpha$  is the angle of inclination with respect to a reference vertical.

[0005] From the phase change  $\Phi$  measured from the apparatus, the angle of the fluid surface with respect to the reference line can be determined using equation (3).

[0006] In the patent form DE 196 10 941 C2 and DE 198 19 610 C1 there are descriptions of types of optical clinometers in which the change in direction of a light ray through reflection at an inclined surface of a fluid is achieved. Thereby, a structure based on one or two dimensional sensor elements is created. From the change in the position of the figure of this structure the inclination is determined.

[0007] From the publication form DE 41 10 858, it is known that there is a double axial clinometer in which the geometric figure

is projected through an inclination sensitive and ray deviating sensor on to a linear array. The sensor contains a fluid the position of which relative to the device leads to a change in the deviation of the projection of the figure on the linear array.

[0008] The international PCT - patent application number PCT / EP03 / 05206 describes an optical clinometer in which a boundary layer is designed between two media in a camera. From the parameters of this boundary layer, for e.g. position and form, the inclination of the device using this clinometer could be determined.

[0009] The type of fluid used in this genre of clinometers is such that the inclination dependent position of the surface of the fluid is directly or indirectly used to derive the angle of inclination. There arises however a disadvantage that the use of a fluid surface creates several problems which are mainly due to the dynamic characteristics of the fluid. For example as a result of vibrations or through convection deviations of the fluid surface, from an ideal surface, a corresponding change of the reflection or transmission radiation occurs.

[0010] As a result of these changes, there are several disturbances in the wave front. A statistic unevenness of the fluid surface leads to a place dependent varying angle of the fluid surface which does not permit the assumption of an

inclination angle  $\alpha$  for the entire surface. In addition, in case of acceleration in the medium or in the case of thermal gradients, there would be deformation of the fluid surface. These are modeled as aspherical aberrations of a high order but have not been considered so far. As a result of a distorted surface, the figure of a structure on the sensor is also distorted, unclear or with bad contrast, so that the measurement is problematic.

[0011] Attempts so far to compensate for these included manipulation measures for directly reducing the effects such as for e.g. the use of down times in which the clinometer is warmed after startup. Alternately, there are device side constructions such as for e.g. a large enough dimensioning of the fluid container. Apart from these, the possible areas of application of a clinometer are also reduced such as for e.g. with reference to the allowed vibrations or acceleration.

[0012] The objective of this invention are in general in improvements of this genre of optical clinometers.

[0013] One of the special objectives is to design a clinometer which has an improved measurement accuracy.

[0014] Further objectives are in the miniaturization of an optical clinometer of this genre and in the simplification of its design.

[0015] An additional objective is in the development of a clinometer in which the time related constraints especially due to thermal effects can be avoided or reduced.

[0016] An additional objective is to device a clinometer which has a broader application than the current state of technology especially considering the mechanical requirements as a result of vibrations.

[0017] An additional objective is in the development of a procedure that allows an algorithmic or electronic recording of the disturbances in the wave front in a clinometer.

[0018] An additional objective of this invention is to guarantee a compatibility with the geodetic or construction related devices. This is especially relevant to the use of available electronic components as processing devices.

[0019] A further objective is the development of a wave front sensor for clinometer which allows the measurement of an enlarged angle and/or an increased resolution and/or has an increased dynamic region.

[0020] The objectives have been achieved in an innovative manner through the characteristics of the claims 1 to 13 and 20 or through the characteristics of the sub claims.

[0021] The present invention refers to an optical clinometer. Radiation is generated from a radiation source with the help of which a wave front is drawn on a detector through a medium whose

position is dependent on the inclination. The detector could be designed as a single or multi dimensional and especially flat camera. The medium is captured through a container. This container could probably be made out of a dose for example for capturing the fluid. The diagram, therefore, should not correspond to an optically exact diagram. The lighting of the container is achieved with at least one of either the first medium contained in it or the reflection of the radiation on the surface or the boundary layer of the medium after the detection of the wave front. The lighting is so achieved that the inclination can be derived from it.

[0022] The structure can be increased by the radiation externally for e.g. through a blend or a transmission/reflection code. Alternately, it could also be made of one of the structures inherent in the radiation. What is important is a structure of the radiation field which remains unchanged in the diagram on the detector even after a change effect with the inclination dependent medium. This is such that a conclusion can be achieved on the position of the medium. The inclination is therefore determined with respect to a reference line which serves as a reference and generally combines with a reference dimension of a device such as the reticule.

[0023] The radiation used could be in the visible as well as the invisible spectrum and is normally determined based on the

technical and physical parameters of the radiation source, medium and detector. Apart from traditional radiation sources such as lamps, there could also be other types of sources of radiation such as light emitting diodes or lasers, especially half lead lasers. Depending on the design form, the medium is lighted with this radiation or the medium serves to reflect the radiation.

[0024] Examples of fluids which can be used as media are mercury, water or silicon oil. For the determination of the position of the medium, the reflection at a boundary layer as well as illumination through the medium or a combination of both can be used.

[0025] The picture of the structure is projected on the camera after this reflection and/or transmission and then captured and converted to electronic signals. An appropriate camera for this purpose is a CCD or a CMOS. Such a camera is especially a CMOS Monochrome - Picture sensor ADCS 2120 made by Agilent. This has a field of 640 x 480 pixels.

[0026] The signals generated from the camera are analyzed with the help of a processor and evaluated considering the inclination of the device. An individual or customized component can be used in this case. Alternately, even existing components of other devices could be used. For example the functionality of this processing unit could be carried over from a clinometer

built in a distance measurement device or even from the electronics used in the case of distance measurement. Similarly, it is possible to use the radiation sources used for other purposes in this device for radiation generation. So, for example, a part of the laser light used for distance measurement in a distance measurement device could be coupled and eventually used for the diagram after scattering or widening the radiation.

[0027] Disturbances of the change effect of the radiation field with the medium can be taken into consideration in this innovative manner through an analysis of information through the wave front of the radiation. And thus the influence of the disturbed fluid surface can be compensated for. Thus, there are different procedures available for algorithmic or switching technique related conversion.

[0028] The lighting of the structure is carried out in an advantageous way with a flat or slightly spherical wave, which can be seen after the change effect with the medium aberrations. The aberrations are created as a result of unevenness of the surface of the medium or even through inhomogeneities in the interiors of the medium which are for example, generated by convection. These disturbances in the surface or the interior of the medium arise out of say, temperature gradients during the initiation phase of the device or are enhanced as a result of external influences such as vibrations. In order to contain

these influences within a tolerable zone, the container dimensions are chosen to be large enough in the clinometers as per current state of technology. As a result, the miniaturization is pushed to the boundary. An additional or alternative measure is to consider the downtime of a clinometer during which turning or a balancing procedure takes place and the measurement accuracy is reduced.

[0029] The innovative clinometer uses a detector which is designed as a wave front sensor or contains a wave front sensor for capturing information through the wave front. In order to avoid further damage to the drawing quality, it is advantageous to choose the radiation flow in the medium so that it is perpendicular to the surface of the medium and after leaving the medium it meets the wave front sensor.

[0030] An example for a suitable wave front sensor is a Shack - Hartmann - Wave front sensor (SHS) although in principle, other types of sensors could be used as per the innovation. A Shack - Hartmann - Wave front sensor has a micro lens array through which a multiple number of sub apertures can be generated. The micro lenses can therefore be arranged either in the form of a straight line and thus in a linear form or in the form of a matrix and thus in a surface form. With a suitable choice of the lighting width of the micro lens array, a satisfactory level of angular resolution can be achieved. With enough knowledge of the

wave front, the disruptive aberrations of the wave front can be calibrated and removed. Mostly, the lenses are arranged in an equidistant manner in a two dimensional lateral arrangement so that a matrix of focal points is generated. The change of each focal point from the axis of the lens is a mass for the tilting of the wave front within the aperture of these lenses. With appropriate algorithms, the entire wave front could be reconstructed from the sum of the focal points. Thus, through the capture of the wave front with several sub apertures, a complete reconstruction of the topography of the oil surface or the wave front can be achieved or only a part of the information could be used such as to choose the pixels of the detectors with the unchanged image.

[0031] For the detection of the position of the focal points, CCD or CMOS sensors could be used whereby each sub aperture would contain an array of at least 2X2 pixels. In this derivation it corresponds to a quadrant sensor. As per the resolution requirement, even a higher number of pixels per sub aperture could be utilized. To increase the derivation speed and to reduce the noise, a combination to a higher structure of pixels could be achieved. Similarly, the use of even a purely linear and line type wave front sensors is suitable.

[0032] With the use of a wave front sensor even the apparatus cost could be brought down since no 4f - optics would have to be

used and the micro lens arrays are simple and can be manufactured through cost effective replication procedures.

[0033] With the help of the wave front sensor, the information of the parameters and the structure of the wave front is made available. This can be used algorithmically or with the help of switching techniques for the purpose of compensation for aberrations. Firstly, the wave front could be analyzed with respect to its form function completely or partially. In general, the wave front  $W(x, y)$  can be approximated with the help of a sum of polynomials of a higher order. A possible derivation is possible with the help of Zernike polynomials. Thereby, the wave front  $W(x, y)$  is a sum with coefficients  $C_n$ :

$$W(x, y) = \sum C_n Z_n(x, y) \quad (4)$$

The first 10 polynomials  $Z_n(x, y)$  is defined in the Cartesian system as follows:

$$Z_1(x, y) = y$$

$$Z_2(x, y) = x$$

$$Z_3(x, y) = -x^2 + y^2$$

$$Z_4(x, y) = 2xy$$

$$Z_5(x, y) = -1 + 2x^2 + 2y^2$$

$$Z_6(x, y) = -3x^2y + y^3$$

$$Z_7(x, y) = -x^3 + 3xy^2$$

$$Z_8(x, y) = -2y + 3x^2y + 3y^3$$

$$Z_9(x, y) = -2x + 3x^3 + 3yy^2$$

$$Z_{10}(x, y) = x^4 - 6x^2y^2 + y^4$$

[0034] Thereby, the special optical errors and corresponding coefficients can be arranged for e.g.  $Z_5$  with respect to astigmatism.

[0035] Along with the reconstruction of the wave front, even the pure recognition of pixels could be achieved whose aperture comprises of a plane section or a part of the wave front without any bending or disturbance. Thus, it is also possible that only the content of such pixels is used for an evaluation and the disturbances are removed very near to the hardware.

[0036] In addition to this, even the local information about the course of the wave front could be corrected. The appropriate algorithms such as wave front transformations are available, which allow a reduction in the noise.

[0037] To increase the performance characteristics of the optical clinometer, an innovative wave front sensor could be used. In the case of this innovative wave front sensor, the resolution and absolute determination of the wave front could be increased through the arrangement of the wave front sections.

Wave front sensors based on the Shack - Hartmann principle and current state of technology utilize only the position determination of the focal point within the respective sub apertures. The resolution is therefore constrained by the lighting width of the individual micro lenses and the number of micro lenses as well as the pixels arranged in each of the respective micro lens. In addition, there is no possibility of absolute determination of the wave front without modification of the micro lens arrays as a result of dark spots. In the case of this innovative wave front sensor, a diffraction element is positioned before the micro lenses and as a result, instead of a focal point in the sub aperture, multiple focal points of the generated bending arrangements or even the entire bending image could be considered for the determination of the exact wave front. Thus, apart from the pixels arranged to each micro lens, additional pixels of the detector could be illuminated. A separation and arrangement of the lighting structures with the respective sub apertures can be realized with the help of an algorithm with a known procedure. The advantageous part is a distinct formation of the bending structures which can be realized through large changes in intensities such as in the case of a Bar code. There are even good characteristics with respect to code - reconstruction such as the use of an M sequence which could be considered.

[0038] With the help of this innovative procedure, the innovative equipment can reduce the tuning phase after switching on the device. It is also possible to reduce the dimensions of the container for the medium so that there is a miniaturization of the clinometer.

[0039] The innovative procedure and the innovative equipment are explained more in detail through a pure example in the following with the help of a figure which has a schematic diagram of the example. Individually the figures show:

Fig. 1 a-b: A schematic diagram of a clinometer with reflection as per the state of technology

Fig.2: A schematic diagram of a clinometer with transmission as per the state of technology

Fig. 3 a-b: A schematic diagram of the innovative arrangement and effect of a wave front sensor;

Fig. 4: A schematic diagram of the innovative use of a wave front sensor

Fig. 5: A schematic diagram of a first design form of an innovative clinometer in the side view

Fig. 6: A schematic diagram of a second design form of an innovative clinometer in the side view

Fig. 7a-b: A schematic diagram of a third design form of an innovative clinometer in the side and top views

Fig. 8: A schematic diagram of a form of the invented procedure and

Fig. 9: A schematic diagram of the innovative wave front sensor.

[0040] Fig. 1a-b describes a clinometer as per the state of technology which is based on the principle of reflection. Fig 1a shows the conditions in the case of a horizontal arrangement of the clinometer in contrast to fig. 1b which explains the conditions in the case of a slight inclination. In fig. 1a the radiation S emitted by a radiation source falls on a line code as the structure 1 to be formed and is passed through a prismatic body 2. There it is reflected off an inner surface and bent towards the fluid layer 4 on the surface of the prismatic body 2. There is a further reflection at the surface of the fluid layer 4 adjoining the prismatic body 2 and there is a

subsequent image on the detector 3. This is shown here in the example as a linear array. The structure 1 is made on the detector 3 as an image B. The position of the image B is thereby dependent on the angle of the surface of the fluid layer 4 adjoining the prismatic body 2 with respect to the prism 2.

[0041] Fig. 1b has a situation similar to that shown in fig. 1a in which the fluid layer 4 contains a wedge-shaped cross section as a result of the inclination. The surfaces of the fluid layer 4 which are adjoining the prismatic body 2 do not run parallel to each other but are at an angle to each other. The radiation S reflected at the inner surface of the prism now meets another surface S of the fluid 4 as against what is shown in fig. 1a and is thus projected on the detector 3 under another angle. Thereby, the image B of the line code is also shifted as structure 1. From the dimension of the shift of the image B it is possible to derive the inclination.

[0042] Fig. 2 shows a schematic representation of a clinometer with transmission as per the state of technology. A line code is shown as structure 1 over an optical system with at least one collimating lens 5' and medium 6 and through an optical system with at least one focusing lens 5' on to detector which is not explicitly drawn here. The plane or slightly spherical and undisturbed wave front WF1, after passing through a transmissible line code, experiences a change in form because of

the unevenness of the surface or as a result of inhomogeneities within the disturbed medium 6. As a result, there is a disturbed wave front WF2. This change of the undisturbed wave front WF1 into the disturbed wave front WF2 leads to a distorted image B' on the detector. This can be offset, for example, through the influence of the contrast of the structure 1 so that a differentiation within the characteristics of structure 1 is made more difficult or worsened.

[0043] The innovative arrangement and working of a wave front sensor is explained schematically with the help of fig. 3 a-b. Fig 3a shows the situation with an undisturbed medium 6' and fig. 3b shows the situation with a disturbed medium 6.

[0044] In fig. 3a, the radiation falls on an undisturbed medium 6' and passes through it, whereby the passing occurs in a vertical direction to the surface so that there is a reduction in the losses and aberrations. After passing through the same, the wave front WF3 is undisturbed and mostly plane. When the radiation meets the wave front sensor which has multiple micro lenses 7 with sub apertures arranged in them, the radiation of each sub aperture is captured with the camera 8. Since the wave front WF3 has a planar course, it contains the same parallel course on the whole and therefore identical angle against the wave front sensor. Thus, the focal points FP on the camera 8 are

equidistant and captured on the optical axis of each micro lens 7.

[0045] Fig. 3b shows the situation for a disturbed wave front WF4 which after passing through the disturbed medium 6 shows aberrations and an uneven course. The micro lenses 7 project the radiation captured on its respective sub apertures again on to the detector 8. Since the angle of the captured wave front section is focally different for each of these sub apertures, the corresponding focal points FP contain different distances. In the case of the sub apertures, which capture a non parallel wave front section, the focal points FP and the optical axes do not come together. Thus, there is a deviation. Since region associated with each sub aperture of the camera 8 has multiple pixels, the location of the focal point FP could be resolved and thus the angle of the wave front section could be derived.

[0046] These relationships are once again clarified in fig. 4 and the dimensions required for an innovative usage are shown schematically. The wave front section captured from the sub apertures of the individual micro lenses 7 are recorded in the camera 8. Depending on the concrete course, the focal point FP and optical axis OA could be together or different from each other. For example (in this example), a focal point FP on the left of the optical axis OA derives a radiation which falls on the right as a result of which, the corresponding inclination of

the respective wave front section could be derived. The magnitude of the distance between the focal point and the optical axis OA reveals a function of the angle of the wave front section.

[0047] Fig. 5 shows the first design form of the innovative optical clinometer. With the help of radiation S which is transmitted by a light emitter as a local radiation source 11, a transverse reflecting surface of the housing of the innovative clinometer is illuminated. The detector S' has a wave front sensor with a camera 8' and a pre-designed array of micro lenses 7. On the side of the camera 8' which is opposite to the side on which the radiation falls, is a processing unit 9'. With the help of such an arrangement of components, it is possible to design a really flat construction for the clinometer.

[0048] In fig. 6, there is a schematic diagram of a second design form of an innovative optical clinometer with the integration of all components on a disc as a common base 12 as shown in the side view. A visible or invisible radiation S is emitted through the radiation source 11' at a direction perpendicular to the base 12. The radiation S is collimated through a lens 5" and is bent with the help of one bending element 13' and a second bending element 13" so that it falls vertically on the base 1. In the region of the falling radiation, there is a container on the base 1 for the medium 6'

with a first surface oriented towards the base and a second surface oriented towards the second bending element 13". Between the base 12 and the container or its first surface, there is a detector 3" with a wave front sensor from a camera 8" and a pre-designed array of micro lenses 7. The detector 3" is coupled with a processing unit 9". On grounds of saving space, the components required for radiation generation, radiation transmission and for receiving the radiation are on one side of the base 12 and the processing unit 9" is on the other side of the base 12. In principle, another arrangement of the components or the processing unit 9" could be chosen. This arrangement, therefore, provides the advantage of integration of all electronic components on one common base 12 which, for example, could also be designed as a lead disc. Therefore, a simple and mechanically robust construction could be realized. The bending elements 13' and 13" could be designed as reflecting elements such as for e.g. prisms or mirrors. Fundamentally, a mounting on a common base 12 could be avoided by directly mounting the components on each other which is shown in the second design form in fig. 5 or fig. 7a-b.

[0049] Fig. 7a-b shows a third design form of an innovative optical clinometer with coaxial arrangement of all components. The base 12' is mostly designed in a u-form and takes the radiation source 11" between the two arms. The radiation source

emits the radiation S which is collimated with a lens 5''. The collimated radiation S is then transmitted through the medium 6' which is brought on to a detector 3'' directly or indirectly in a container. The detector has a wave front sensor with a camera 8'' and a planar arrangement of micro lenses 7. There is a processing unit 9'' on the side of the base 12' which is opposite to the detector 3''.

[0050] Fig. 7b shows the top view of the arrangement of micro lenses 7 of a wave front sensor in the case of the third design form of an innovative clinometer. In this case, the radiation source, lenses and container with the medium are removed from the diagram. The radiation is depicted on the camera 8'' of the detector and is through the planar arrangement of micro lenses 7.

[0051] A possible form of the innovative procedure is clearly explained in fig. 8. In the case of a detector construction as per the principle explained in fig. 4 with a wave front sensor, the individual pixels of the camera 8 are only then considered in the processing when the focal point FP1 overlaps with the optical axis OA of the respective micro lenses 7 or if their deviations from each other lies within the specified tolerance range. For evaluation only those pixels are taken and further processed which satisfy this requirement so that only that part of the image is used which can be captured without any

aberration. Thereby, it is possible to correlate different pixels with each other. The pixels can especially be combined to form larger super structures. In order to obtain an improvement in the optical parameters, even the image so obtained could be used with known image processing procedures.

[0052] Fig. 9 shows a design form of the innovative wave front sensor in a schematic manner. A diffraction element 14 is arranged before the micro lens 7 through which the radiation coming from the wave front WF4 is bent. This diffraction element could probably be a hologram, a grid, especially a Dammann grid, or another gradient optic structure. Apart from the direct positioning over the micro lenses 7, there could also be an arrangement at another position in the transmission path for e.g. on a bending mirror of fig. 6 or in direct contact with the medium for e.g. on a glass of the container. As a result of the bending, there could be multiple intensity structures 15 on the camera 8 apart from or in addition to undisturbed focal point FP2. These are correlated to each other. Depending on the derivation of the diffraction element 14 and the structure of the wave front WF4, these structures could be drawn even in the regions which in the case of a wave front sensor without a diffraction element 14 would have had another sub aperture arranged exclusively for it. Apart from the higher bending arrangements, these structures could also represent extended

Fourier images of the diffraction element. Therefore, it is possible to use a larger region of the camera 8 for each sub aperture for the purpose of detection and thus a higher resolution, larger detectable angle zones and/or a higher dynamic zone could be achieved.

[0053] The displayed design forms only provide examples for the innovative realization and therefore are not to be considered as comprehensive and constrained. In addition, a specialist could develop further innovative design forms under the usage of other radiation or bending elements such as for e.g. prisms, tuning surfaces or light emitters, or alternative forms of the detector and the wave front sensors.

[0054] In these figures, the lenses of the wave front sensor and their numbers and dimensions are purely schematic. In the real design form, the number of lenses is usually higher so that a higher resolution of the position or the angle could be achieved.

#### **Patent claims:**

##### **1. Optical clinometer with**

- A radiation source (11, 11', 11'') for generation of radiation S especially a half lead laser or an LED

- A medium (6, 6') whose optical boundary layer is dependent on inclination
- A detector (3', 3'', 3''') preferably with a CMOS or CCD Micro camera to capture images and change the image in signals
- A processing unit (9', 9'', 9''') for the determination of inclination

Whereby the radiation source (11', 11'', 11''') and the detector (3', 3'', 3''') are so arranged that the wave front (WF2, WF3, WF4) is associated with at least one part of the medium (6, 6') directly or indirectly and is captured in reflection and/or transmission on to the detector (3', 3'', 3'''), which means that the detector (3', 3'', 3''') has a wave front sensor or the detector is designed as a wave front sensor.

2. Optical clinometer as per claim 1 means that the medium (6, 6'') has an inclination dependent surface especially like a fluid.

3. Optical clinometer as per claim 1 or 2 means that the radiation source (11', 11'', 11'''), medium (6', 6'') and detector (3', 3'', 3''') are so arranged that the radiation (S) while passing through the medium (6, 6') is mostly perpendicular to at least one of the surfaces of the medium (6, 6').
4. Optical clinometer as per one of the above claims means that the detector (3', 3'', 3''') has at least one diffraction element (14) whereby it is arranged on an array of micro lenses (7).
5. Optical clinometer as per one of the above claims means that the detector (3', 3'', 3''') is designed as a Shack - Hartmann - wave front sensor or contains a Shack - Hartmann - wave front sensor.
6. Optical clinometer as per one of the above claims means that the detector (3', 3'', 3''') is directly or indirectly brought on to the container with the medium (6, 6').
7. Optical clinometer as per one of the above claims means that the detector (3', 3'', 3''') has a two dimensional resolving detector surface, especially with a one to one surface of the

medium (6, 6') in parallel orientation of the detector surface.

8. Optical clinometer as per one of the above claims means that the radiation source (11, 11', 11'') and the detector (3', 3'', 3''') are arranged on a common base (12, 12') which is preferably a lead disc.

9. Optical clinometer as per claim 8 means that the radiation source (11, 11', 11'') and the detector (3', 3'', 3''') are so arranged so that the radiation (S) is emitted perpendicular to the surface of the base (12, 12') and the receiving direction of the detector (3', 3'', 3''') is oriented perpendicular to the surface of the base (12, 12').

10. Optical clinometer as per at least one of the above claims means that during the transmission from the radiation source (11, 11', 11'') to the detector (3', 3'', 3'''), there is at least one bending element (13', 13'').

11. Optical clinometer as per at least one of the above claims means that during transmission from the radiation source (11, 11', 11'') to the detector (3', 3'', 3'''), there is at least

one diffraction element and/or a gradient optical element  
(10) especially a Fresnel lens

12. Geodetic devices - especially distance measurement devices  
or Lot stock, with a clinometer as per one of the  
requirements from 1 to 11.

13. Procedure for measurement of the inclination of a device,  
especially a geodetic device with

- A radiation source (11, 11', 11'') for generation of  
radiation S especially a half lead laser or an LED
- A medium (6, 6') whose optical boundary layer is  
dependent on inclination
- A detector (3', 3'', 3''') preferably with a CMOS or CCD  
Micro camera to capture images and change the image in  
signals
- A processing unit (9', 9'', 9''') for the determination of  
inclination

Whereby the radiation source (11', 11'', 11''') and the detector (3', 3'', 3''') are so arranged that the wave front (WF2, WF3, WF4) is associated with at least one part of the medium (6, 6') directly or indirectly and is captured in reflection and/or transmission on to the detector (3', 3'', 3'''), with the steps

- Designing of the wave front (WF2, WF3, WF4) on the detector (3', 3'', 3''')
- Capturing the signals of the detector (3', 3'', 3''')
- Evaluation of the signals and determination of the inclination of the device with the help of the processing unit (9', 9'', 9''')

means that, during the processing of the signal information about the wave fronts (WF2, WF3, WF4), the form function of the wave front (WF2, WF3, WF4) is derived.

14. Procedure as per claim 13 means that during the processing of the signals, an analysis of the deviation of the wave front (WF2, WF3, and WF4) from the wave front (WF1) before a change effect with the medium is carried out.

15. Procedure as per claims 13 and 14 means that during the capture of signals and/or during processing of signals, a reconstruction of the wave front (WF1) before a change effect is carried out with the medium (6', 6)
16. Procedure as per claims 13 to 15 means that during the capture of signals and/or during processing of signals, a choice of individual pixels of the detector (3', 3'', 3''') is carried out, whereby preferably only those pixels are used for the determination of the inclination of the device.
17. Procedure as per claims 13 to 16 means that during the processing of signals, a derivation of the form function with the help of a polynomial function is carried out especially with the use of a Zernike polynomial.
18. Procedure as per claims 13 to 17 means that during the capture of signals and/or during evaluation of the signals, different apertures are correlated with each other.
19. Use of a procedure as per claims 13 to 18 for compensation of vibrations and/or statistical fluctuations of at least one

surface of the medium (6, 6') especially as a result of the convection processes

20. Wave front sensor for the use in an optical clinometer as per one of the claims 1 to 12 with

- A camera (8), preferably one with CMOS or CCD micro camera, for capturing and changing images in signals
- An array of micro lenses (7)

means that the array of micro lenses (7) has at least one diffraction element attached to it

21. Wave front sensor as per claim 20 means that the diffraction element (14) is a hologram or a grid, especially a Dammann grid.

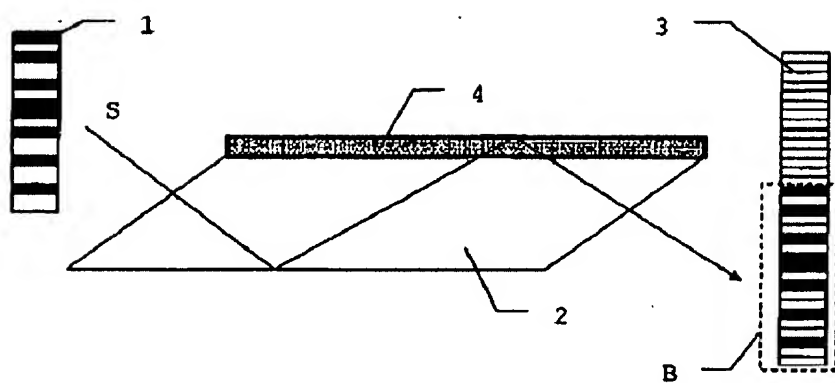


Figure 1a

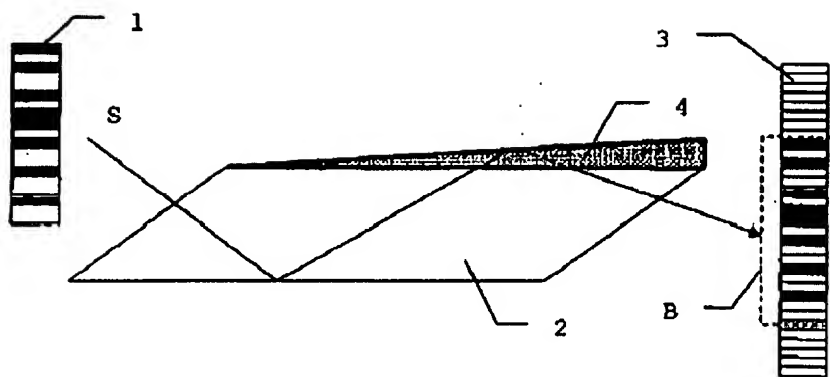


Figure 1b

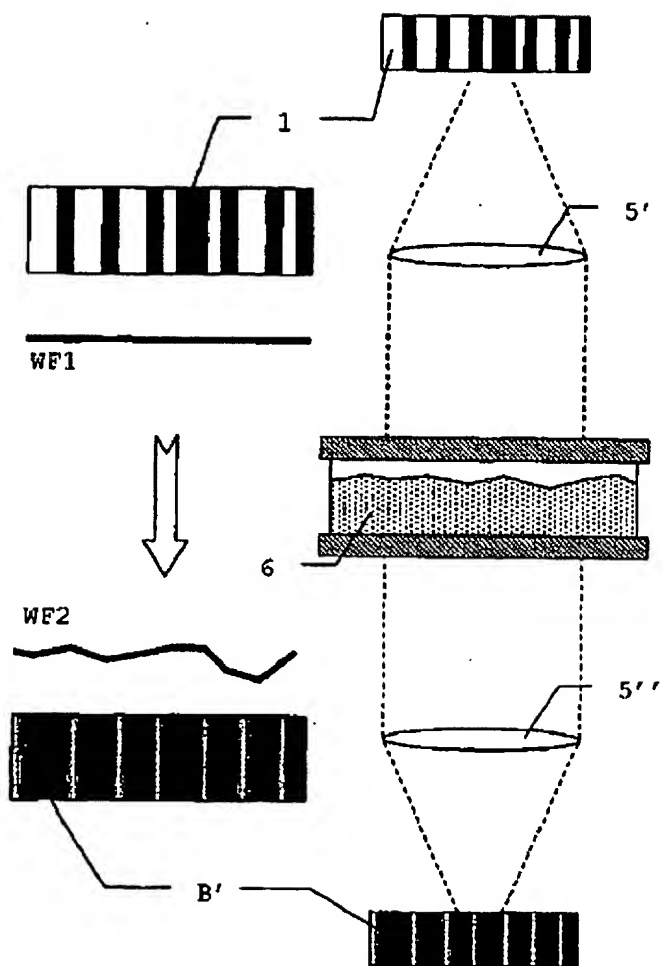


Figure 2

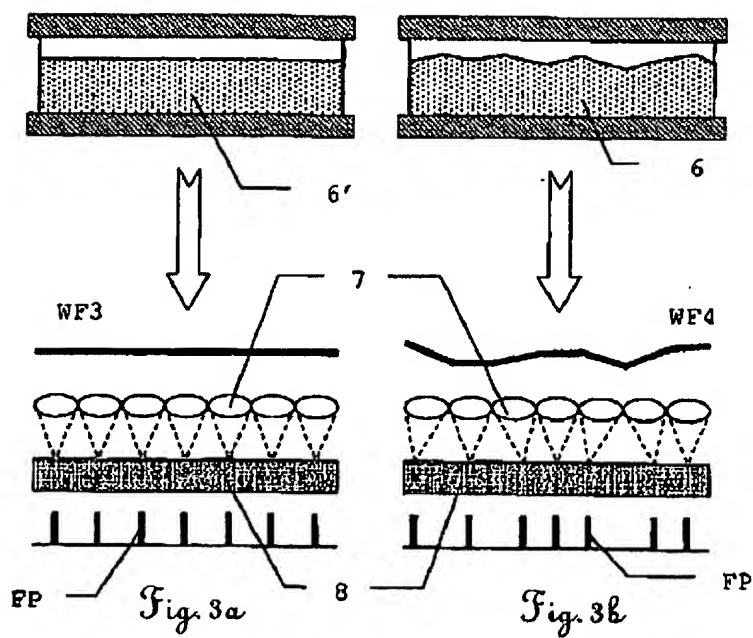


Figure 3a

Figure 3b

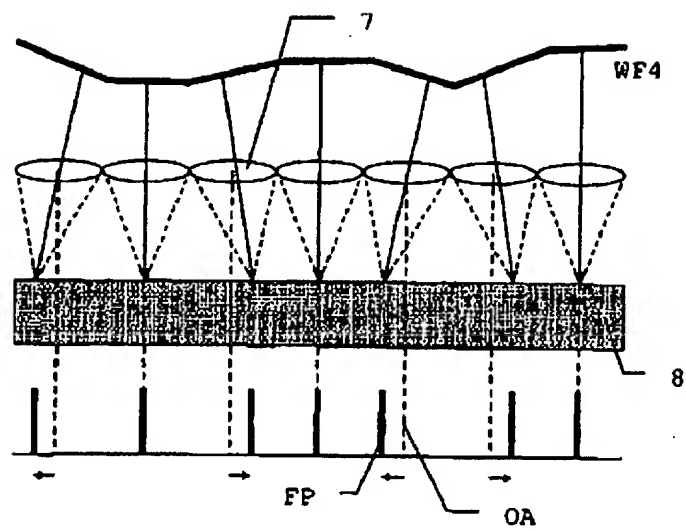


Figure 4

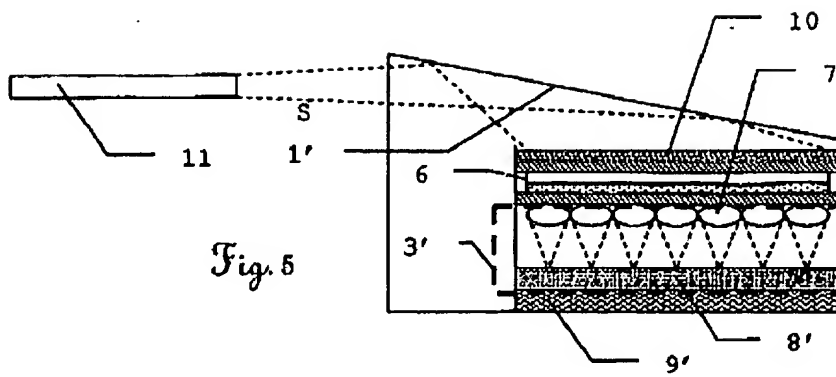


Figure 5

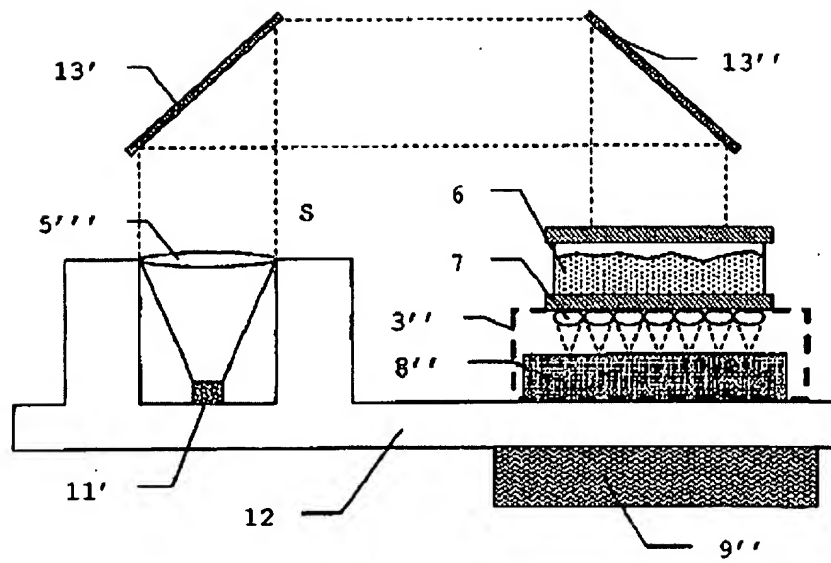


Figure 6

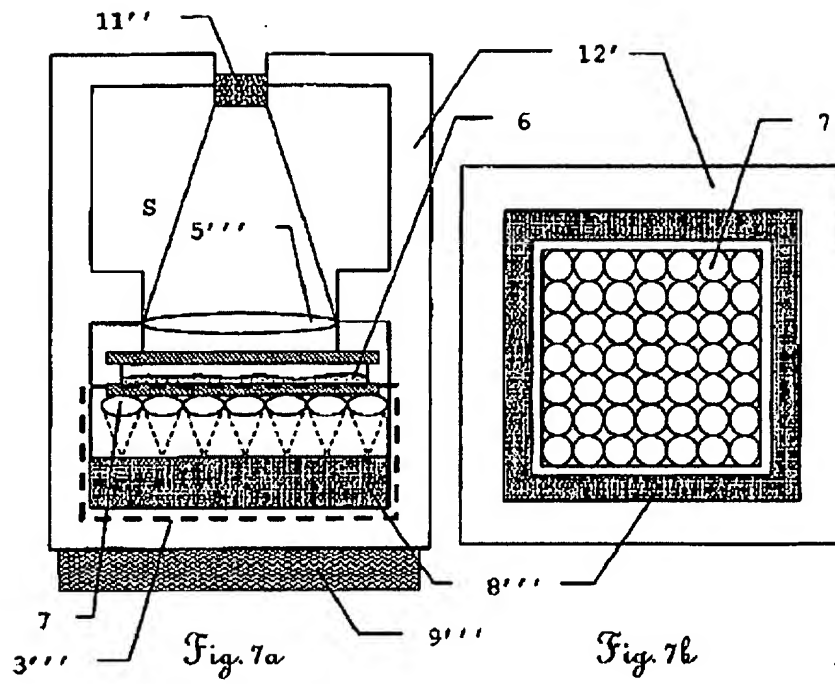


Figure 7a

Figure 7b

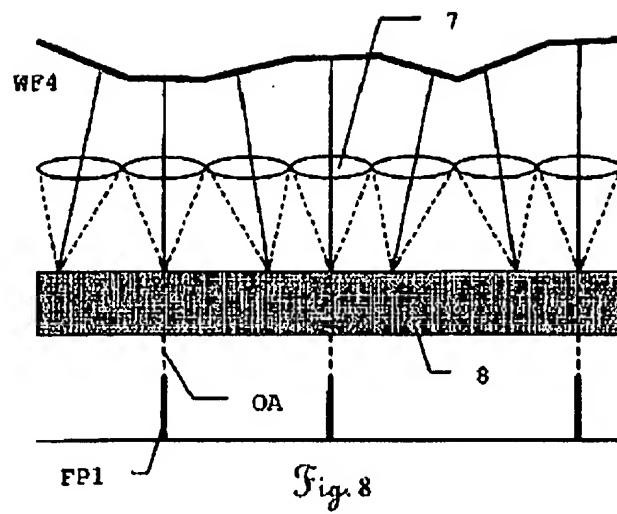


Figure 8

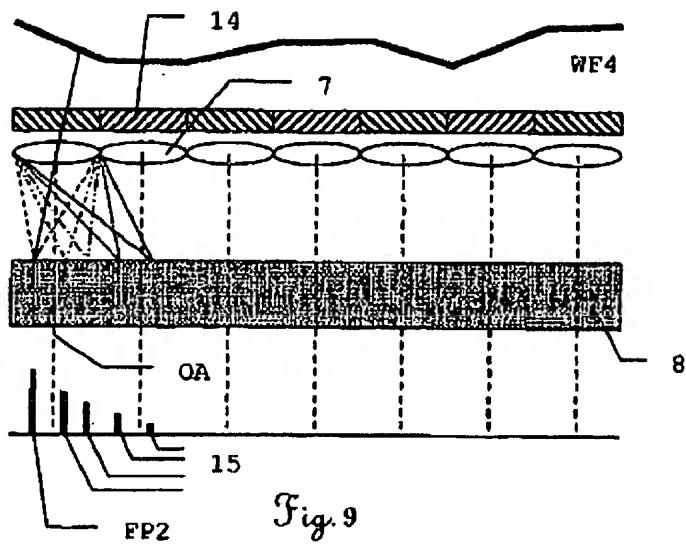


Figure 9

EP 1 491 855 A1

European  
number

Application

EUROPEAN RESEARCH REPORT

Patent Office

EP 03 10 1841

PERTINENT DOCUMENTS			
Category	Description of documents with information, as far as possible, with important portions	Refers to claim	Classification of application
x	DE 198 00 84 4 A (SCHWIDER JOHANNES PROF DR) 15th July 1999 (07.15.99) * Requirements 1, 7*	20, 21	GOIC9/20 GOIC9/06 GO2B26/06
A	DE 196 21 189 A (LEICA AG) 27th November 1997 (11.27.97)  Summary; Diagram 8 * Column 14, Line 6 - line 34 *	1, 2, 6 - 10, 12, 13, 16	
A	US - 4 239 392 A (POHLE RICHARD H) 16th December 1980 (12.16.80)	20	

A	<p>* Summary *</p> <p>US - 6 088 090 A (NAKAMURA          MASAHIRO ET AL) 11th July 2000          (07.11.00)</p> <p>* Summary *</p>	<p>1, 2, 12,          13</p>	
			Domains of research
			GOIC GO2B
The above research report would be used for all patent applications			
Place of research THE HAGUE	Completion of research 12.04.2003	Checked by Hunt, J	

<p>CATEGORY OF THE DOCUMENTS</p> <p>x: of significance standalone</p> <p>y: of significance in relation to another publication of the same category</p> <p>A: technological background</p> <p>O: non-written manifestation</p> <p>P: intermediate literature</p>	<p>T: theories and fundamentals which form the basis of the invention</p> <p>E: old patent document, which has been published now or after the application</p> <p>D: document given with the application</p> <p>L: document provided for other reasons</p> <p>&amp;: member of the same patent family</p>
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ATTACHMENT TO THE EUROPEAN RESEARCH REPORT

ABOUT THE EUROPEAN PATENT APPLICATION NUMBER EP 03 10 1841

The members of the patent family in the patent documents mentioned in the above European research report are given in this attachment.

The information about the family members correspond the state of records in the European patents office.

This list is only for the purpose of information and does not carry any warranty.

12.04.03

Patent document mentioned in the research report	date of publication	members of the patent family	date of publication
Of. 19800844 A	07.15.99 OE	19800844 A1	07.15.99
DE 19621189 A	11.27.97 DE	19621189 A1	11.27.97
	DE	59708671 01	12.12.02
	WO	9745701 A1	12.04.97

				EP	0901608 A1	03.17.99
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US 4239392	A	12.16.80	NONE			
US 6088090	A	07.11.00	JP	10239051 A	09.11.98	

For further details about this attachment: refer to the official publication of the European patents office number 12/82